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Changing of energy consumption patterns from rural households to urban households in China: An example from Shaanxi Province, China

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Abstract

We chose five study sites, from a traditional village, the Laoxiancheng Village, in remote mountainous areas to towns, the Houzhenzi *Xiang* Township, the Mazhao Town and the Zhouzhi County Town, as well as in a modern city, Xi'an in the Shaanxi Province of China, to study differences in energy consumption between rural and urban households and to assess its conservation implications. This study confirmed the prediction of the 'ladder of fuel preferences' theory. Energies used in urban households are more convenient, cleaner, and more efficient than those used in rural areas, where biomass and coal are common fuel. The amount of energy used for entertainment and electric appliances is greater in urban areas, whereas the quantity used for cooking is larger in rural districts. People in Laoxiancheng Village completely depended on fuelwood for cooking and heating. In the Houzhenzi *Xiang* Township, 16.7% household use coal ball, and 23.3% use LPG. Electricity and fuelwood were used in each household. In the Mazhao Town, 96.7% households used crop residue, 90% used coal, about 30% use LPG, and every household used electricity. In the Zhouzhi County Town, of the entire sampled household, 92.7% used coal, 92.7% of household used LPG and 37.5% household used gasoline. In the Xi'an city, of the entire sampled household, 32.8% household used natural gas, 67.2% used LPG; about 34.9% household used gasoline, 48.6% household used electricity and 51.4% used natural gas for heating in winter. In the five study areas, the ratio of each energy source consumed per household was also different. In the Houzhenzi *Xiang* Township, coal took 6.2%, LPG 1.4%, electricity 1.4% and fuelwood 91%. In the Mazhao Town, crop residue took 31.4%, coal 62.2%, LPG 2.2%, and electricity 4.2%. In the Zhouzhi County Town, the importance

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of energy ranked as follows: coal 75.8%, LPG 12.8%, electricity 5%, and gasoline 6.4%. In the Xi'an city, LPG took 17.6%, natural gas 27.3%, gasoline 16.9%, and electricity 38.2%. Comparing total annual consumption, households in villages used more energy compared to the households in cities. The mean of total annual energy consumption was 79.57, 63.07, 37.75, 42.53, and 29.73 GJ in the Laoxiancheng Village, Houzhenzi *Xiang* Township, Mazhao Town, Zhouzhi County Town, and Xi'an City, respectively. We should improve the efficiency of fuel burning and introduce cleaner energy resources, such as biogas and hydropower in villages. For the households in rural areas, it is necessary to substitute coal with other cleaner energy resources and it is more important and urgent for urban households to save energy, considering large population in cities.

Keywords: Biomass; Chemical energy; Village; Town; Countryside; City

Contents

1. Introduction

Energy consumption has long been seen as a critical indicator of socio-economic activity, national economic growth and human impact on the environment [1]. With increasing world population and rising living standards, the demand for energy in the world is continually growing. Energy consumed by households represents a considerable percentage of the energy consumed in the world [2]. Patterns of domestic energy use are closely linked to agro-climatic [3], socio-economic conditions [3–8], such as the level of the user's living standards [8–11], family size, education, farm area per rural household and forest area per household [12]. It is also influenced by government policy, which affects the inequity in fuel and equipment availability among different income groups [13].

Urbanization is a social process of global proportions [14], which is defined in terms of concentrated human presence in residential and industrial settings and their associated

effects [15]. Transformations of economic structure, location and lifestyles have resulted in rapid urbanization and growing demand for modern fuels [7,16]. In some developing countries, the rapid pace of urbanization generates fundamental changes in energy use [17,18].

Since the world energy crisis in 1970s, researches on energy consumption in the rural, domestic sectors of developing countries have gained much attention, such as those in India and South Africa, because the energy consumptions in the rural and domestic sectors directly affect sustainable and balanced economic development [19]. Household energy consumption in rural areas also composes an important part of China's national energy consumption [20]. Researches show the consumptions of electricity and liquidized petroleum gas (LPG) are increasing while that of straw and coal are declining in China, though effective heat use has increased slightly [12,20,21].

Researches on energy consumption in the domestic sector are focused on either rural or urban areas, little is known about the changes in energy consumption patterns from villages to cities. In China, the pace of urbanization is accelerating. The population in towns has more than doubled since the economic reform.[1] Thus, it is necessary to study household energy consumption patterns in both countryside and city and shed lights on the energy consumption changes during urbanization. Our aims are to provide quantitative information about domestic energy use, from villages to large cities, and to assess major characteristics of household energy consumption.

2. Study area and method

2.1. Study area

The administrative hierarchical system of China is composed (in a descending order) of the central government, provinces, cities, counties, towns, *Xiangs* (or townships), and villages. Thus the size (in terms of population and area) and degree of urbanization decrease in the same congruent order. We carried out this study in the Shaanxi Province, central China, where we sampled five sites: the Laoxiancheng Village, the Houzhenzi *Xiang* Township, the Mazhao Town, the Zhouzhi County Town, and the Xi'an City (the capital of the Shaanxi Province) (Fig. 1).

Laoxiancheng Village is a small village located in the center of the Qinling Mountains with an average altitude of 1700 m. "Laoxiancheng" means "old country town" in Chinese. It was the old country town of the Foping Country. Due to gangster rebellions, the country government moved and people fled from the area; the old country town was abandoned [22]. Now, only 153 people of 35 households live there and it is a village under the administration of Houzhenzi *Xiang*, Zhouzhi Country. Laoxiancheng Village was isolated from the outside world until a countryside road from Houzhenzi *Xiang* Township was constructed in 1996. However, the lifestyle in the Laoxiancheng Village has changed little since then. Local people still depend on wood as fuel and virtually no commercial energy resource is used. Climate in Laoxiancheng area belongs to the semi-temperate humid zone; summers are short and cool whereas winters are long and cold.

[1]The data is from the National Bureau of Statistics of China.

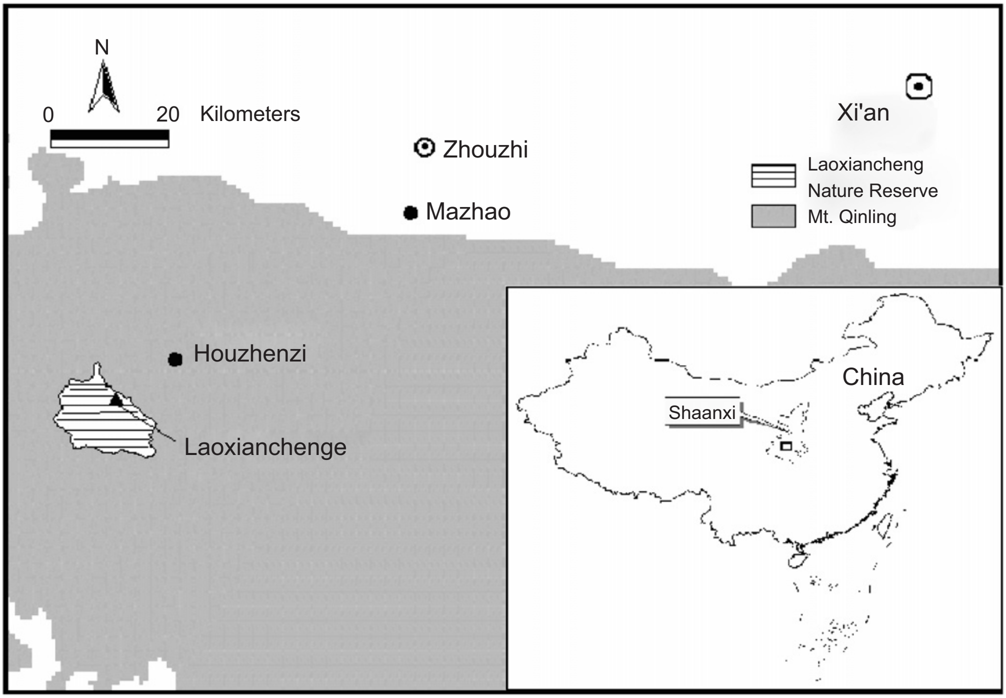


Fig. 1. The location of the Laoxiancheng Village, the Houzhenzi *Xiang* Township, the Mazhao Town, the Zhouzhi County Town and the Xi'an City in China. Note the shaded area indicates the range of Qinling Mountain.

Houzhenzi *Xiang* Township is a small town in the Zhouzhi County Town, average altitude of 1250 m, located 22 km away from the Laoxiancheng Village. There are 62 households with 312 people living in this countryside township and it is accessible by bus. Its climate is similar to that of Laoxiancheng Village with average annual temperatures of 8.4 °C. The average daily temperature is 20.4 °C in July and −4.2 °C in January. Laoxiancheng Village and Houzhenzi *Xiang* Township are located in the mountains and surrounded by the forests of nearby nature reserves.

Mazhao Town is a large town in the Zhouzhi Country with an average altitude of about 600 m. National Highway No. 108 transects the town. It is about 80 km away from the Houzhenzi *Xiang* Township and only 10 km away from the Zhouzhi County Town. There are 20,000 people living in the town and most of them are farmers. Average annual temperature in Mazhao is 13.2 °C.

Zhouzhi County Town is under the administration of Xi'an City. Zhouzhi County Town lies 78 km east of Xi'an city and has an average altitude of 434 m. Its average annual temperature is 13.2 °C. The urban area of Zhouzhi County Town is 6 km^2 and accommodates 60,000 people, most of the residents have full-time jobs.

Xi'an City is located north of the Qinling Mountains, average altitude 400 m, average annual temperature 15 °C. Xi'an was the national capital of 12 dynasties from Western Zhou (1046–771 B.C.) to Tang (618–907 A.D.) in history. The city covers an area of 203 km^2 and hosts a population of 5.1 million.

2.2. Method

We surveyed the family sizes and economic statuses, as well as the types and quantities of energy they consumed from July 2003 to October 2004 (Table 1). The efficiencies of the devices used in each household are given in Table 2.

We collected the data using three methods: pre-designed questionnaire, participant observation and participatory rural appraisal (PRA, [26]). Participant observation was conducted in the Laoxiancheng Village where we stayed with local families to record the daily fuelwood consumption for 7 days each season. PRA was conducted in the Houzhenzi *Xiang* Township and the Mazhao Town; pre-designed questionnaires were used to survey the Zhouzhi County Town and Xi'an City.

We confronted some difficulties in the study. First, some residents do not have records. In such cases, family members estimated the data. Second, in Zhouzhi County Town and in Xi'an City, electricity is also used for cooking, such as electric cooker; however, it was difficult to divide the usage of electricity and the parts used for cooking were very small according to the words of the sampled household in Xi'an city; we only recorded the total electricity consumption. Third, most district heating systems do not have meters to record heat flow in each home. In such cases we referred to the "Energy Conservation Design Standard for Heating New Residential Buildings" [27] to estimate the amount of natural gas used in heating in Xi'an City.

SPSS 13.0 was used to analyze the data. One-way AVONA was used to test the difference of total energy consumption in the five study sites. Kruskal–Wallis *H* and

Table 1
Family size, income and the energy sources of households in the five study areas (Mean ± SE)

Location	Family size	Annual income per household (Yuan, RMB)	Energy sources	*N*
Laoxiancheng Village	$4.13 \pm .30^{a}$	7130 ± 994.66^{a}	Fuelwood	23
Houzhenzi *Xiang* Township	$4.33 \pm .24^{a}$	5493.33 ± 535.88^{a}	Fuelwood; coal; LPG; electricity	30
Mazhao Town	$4.37 \pm .23^{a}$	8666.67 ± 1666.67^{a}	Crop straw; coal; LPG; electricity	30
Zhouzhi County Town	$3.66 \pm .12^{b}$	14919.55 ± 1242.03^{b}	Coal; LPG; gasoline; electricity	96
Xi'an City	$2.73 \pm .04^{c}$	53629.55 ± 2716.83^{c}	LPG; gasoline; electricity	494

Means with the same superscript letters in the same column are not significantly different (Kruskal–Wallis *H* and Mann–Whitney *U*).

Table 2
The efficiencies of the devises used in each household

Energy	Device	Efficiency (%)	Source
Biomass	Traditional stove	10–20	[23]
Coal ball	Traditional stove	26.74	[23]
Gas	Cooker	55	[24]
Electricity	Appliance	>70	[25]

Mann–Whitney *U* were used to test the differences of household characters and energy consumption because we could not transfer data into normally distributed data. Spearman's correlation was used to test the correlation between economic status, household size and consumption of biomass and commercial energy.

3. Result

3.1. Patterns of energy consumption

Energy sources used by each household were different in the five study areas (Table 3). The energy consumption per household in the five study sites is shown in Table 4. The total energy consumption per household per year was divided into three groups: Laoxiancheng Village and Houzhenzi *Xiang* Township, Mazhao Town and Zhouzhi County Town, the Xi'an City (Fig. 2, Table 5).

Table 3
Energy sources used by households in the study sites

Location	Fuelwood (%)	Crop residue (%)	Coal (%)	LPG (%)	Gasoline (%)	Natural gas (%)	Electricity (%)
Laoxiancheng Village	100	0	0	0	0	0	0
Houzhenzi *Xiang* Township	100	0	16.7	23.3	0	0	100
Mazhao Town	0	96.7	90	30	0	0	100
Zhouzhi County Town	0	0	92.7	92.7	37.5	0	100
Xi'an City	0	0	0	67.2	34.9	32.8	100

Table 4
Each energy consumption (GJ/household yr) and its percentage of the total consumption in the five study areas (Mean ± SE)*

Energy source	Laoxiancheng Village		Houzhenzi *Xiang* Township		Mazhao Town		Zhouzhi County Town		Xi'an City	
	Energy consumed	%	Energy consumed	%	Energy consumed	%	Energy consumed	%	Energy consumed	%
Fuelwood	79.57 ± 4.33^{a}**	100	57.51 ± 5.24^{b}	91	0	0	0	0	0	0
Crop residue	0	0	0	0	9.16 ± 1.25	31.4	0	0	0	0
Coal	0	0	$18.40 \pm .98^{a}$	6.2	20.54 ± 2.20^{b}	62.2	34.16 ± 2.07^{c}	75.8	0	0
LPG	0	0	$.78 \pm .30^{a}$	1.4	$.73 \pm .23^{a}$	2.2	$3.92 \pm .26^{b}$	12.8	$2.77 \pm .13^{c}$	17.6
Natural gas	0	0	0	0	0	0	0	0	$10.67 \pm .82$	27.3
Gasoline	0	0	0	0	0	0	$2.94 \pm .79^{a}$	6.4	$7.90 \pm .74^{b}$	16.9
Electricity	0	0	$.79 \pm .15^{a}$	1.4	$1.33 \pm .28^{b}$	4.2	$1.51 \pm .09^{c}$	5	$8.39 \pm .29^{d}$	38.2

*Conversion factors are given in Table 5.
**Means with the same superscript letters in the same row are not significantly different (Kruskal–Wallis *H* and Mann–Whitney *U*).

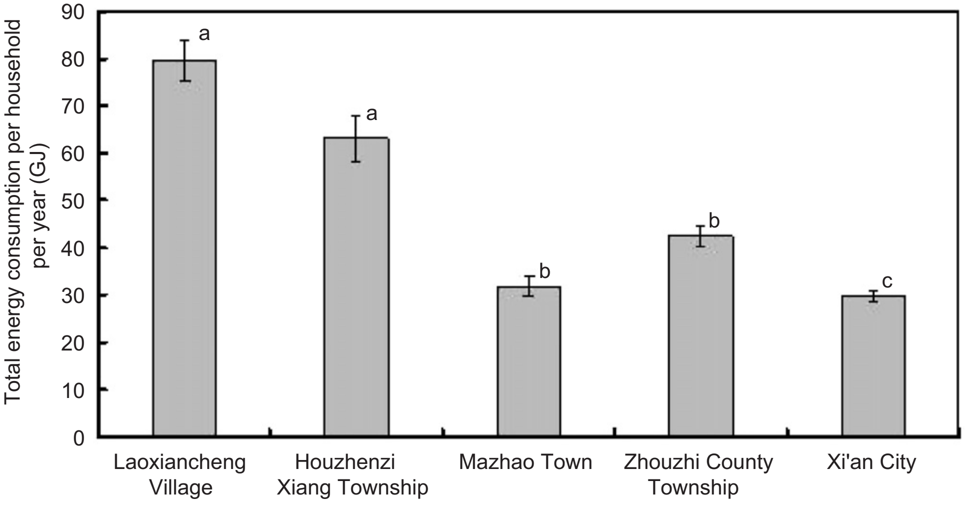


Fig. 2. Total annual energy consumed per household (GJ) in the Laoxiancheng Village, the Houzhenzi *Xiang* Township, the Mazhao Town, the Zhouzhi County Town and the Xi'an City (energy conversion standards are given in Table 5). There was significant difference in the total energy consumption (LSD, $F = 36.108$, $p < .01$; ANOVA), the bars labeled with different letters indicating significant difference.

Table 5
Energy conversion factors

Energy type	Unit	10^7 J
Fuelwood	kg	1.86
Crop residue	kg	1.4
Coal-ball	kg	3.0
LPG	One bottle (15 kg)	75
Natural gas	Cubic meter	.00357
Gasoline	Liter	3.4
Electricity	kWh	.36

3.2. *Total energy consumption and correlations*

Correlations between family size and energy consumption per household were significant. The correlations between family income and energy consumption were not significant in each study site except the Laoxiancheng Village (Table 6), but the correlation between family income and biomass consumption of the total sampled households was significant (Spearman's correlation, $R = -.513$; $p < .01$; Fig. 3(a)), and the correlation between family income and commercial energy consumption of the total sampled households was also significant (Spearman's correlation, $R = .110$; $p < .01$; Fig. 3(b)). Although the model formulas given in Fig. 3 did not simulate well, they still could reflect the affluences of family income to the biomass and commercial energy consumption in households.

Table 6
Correlations between family size, family income and biomass energy, commercial energy consumption

Parameter	Laoxiancheng Village	Houzhenzi Township	*Xiang*	Mazhao Town		Zhouzhi County Town	Xi'an City
	Biomass	Biomass	Commercial fuel	Biomass	Commercial fuel	Commercial fuel	Commercial fuel
Family size	$R = .456^{*}$	$R = .337$	$R = -.250$	$R = .603^{**}$	$R = -.306$	$R = .264^{**}$	$R = .143^{**}$
Family income	$R = .467^{*}$	$R = .062$	$R = .331$	$R = .159$	$R = .114$	$R = .192$	$R = .056$

*Correlation is significant at the .05 level (2-tailed).
**Correlation is significant at the .01 level (2-tailed).

3.3. Spectrum of energy consumption

Energy is used for cooking, heating in winter, lighting, and entertainment; the energy consumption spectra of the households in each study area were different (Fig. 4).

4. Discussion

4.1. Choice and consumption of energy source

Energy transition theory suggests that there is a 'ladder of fuel preferences' from low-quality biomass based fuels to more efficient and versatile modern fuels such as kerosene, LPG and electricity [28]. Our research confirms this theory: as income increases with urbanization, the energy resource people choose shifts from low quality biomass to high quality commercial fuels.

In the Laoxiancheng Village, because of meager transportation conditions and poor economic condition, commercial energy sources like LPG and coal are not available. Instead, the free and easy-to-gain energy source such as fuelwood is the one primarily used by the village's residents. Lack of alternative energy sources, easy access to fuelwood and people having time to collect fuelwood in the bush all superimposed on the energy use pattern in the Laoxiancheng Village.

There exist more alternative commercial energy sources in the Houzhenzi *Xiang* Township than in the Laoxiancheng Village. However, the consumption of commercial energy still only makes up a small percentage of the total energy used, due to the town's poor economic level. Both Laoxiancheng Village and Houzhenzi *Xiang* Township are near forests, thus fuelwood remains as their most important energy source.

Mazhao Town is an agricultural area and lies far from any forest. Most households use these crop residues as fuel. However, biomass is not enough as energy source for the local community; many households also use coal. In addition to coal, electricity and LPG are popular household energy sources in Mazhao. Nevertheless, the town's economical status still prevents extensive access to commercial energy sources like LPG and electricity.

In the Zhouzhi County Town, biomass sources like fuelwood and crop residues are not available. Similar to the Mazhao Town, coal is the most important energy source for the households. LPG and electricity are commonly used as well, and the ratio of their

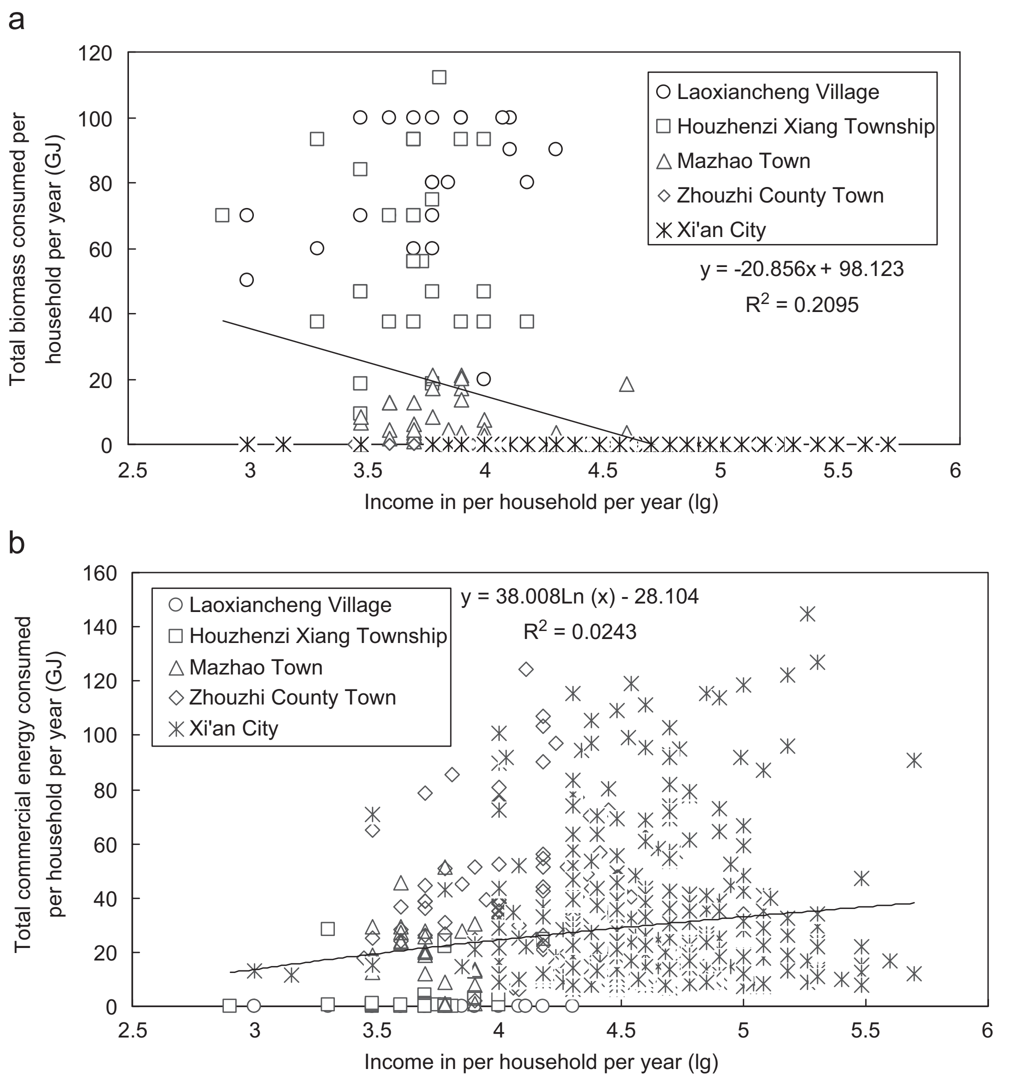


Fig. 3. The correlation between total biomass consumption (a) and commercial energy consumption (b) per household per year and the family annual income in these five study sites.

consumption per household is much more than that of the communities previously described; this is likely due to the different lifestyle and the improved economic status of the residents in the town.

Among all sampled households in Xi’an City, none used coal; instead they used more efficient and cleaner commercial energy sources like LPG, natural gas, gasoline and electricity. According to the statistics of the municipal government in Xi’an City, the number of households using coal is decreasing year by year in the city. The most important energy is electricity due to the augmented use of electric appliances, which reflects the higher economic status of the residents and their lifestyles [28].

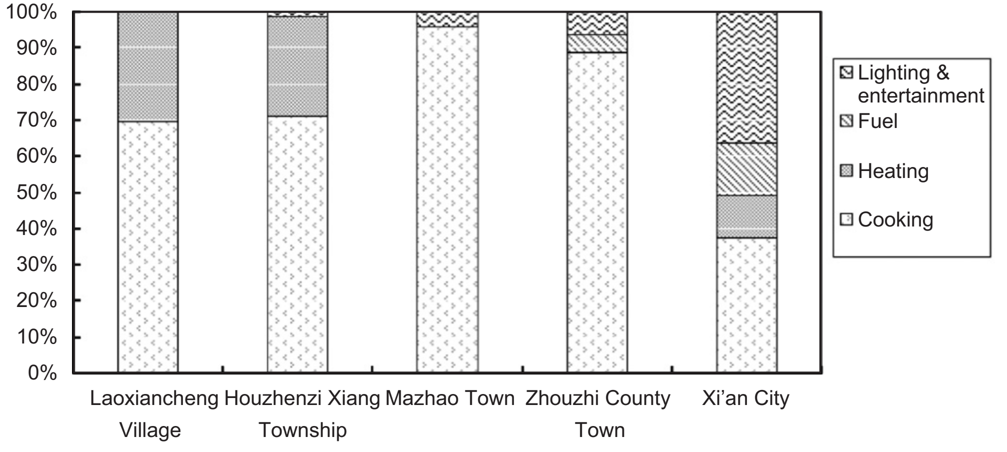


Fig. 4. Energy use pattern in the domestic sector of the five study sites.

4.2. *Annual energy consumptions*

Households in the Laoxiancheng Village have the highest annual energy consumption, followed by those in the Houzhenzi *Xiang* Township, Zhouzhi County Town, Mazhao Town, and then Xi'an City.

In the Laoxiancheng Village, the main energy resource is fuelwood. There are virtually no limitations on wood collection, except that the villagers are prohibited to cut trees with a diameter larger than 10 cm. Laoxiancheng locates in high altitude area with the longest winter and lowest annual mean temperature among all study sites. People have to heat their houses for nearly half a year. In the village, using of traditional stoves still prevail, which only have energy transformation efficiencies of 10–20%. The energy transformation efficiency of stove for fodder is even lower. Therefore, local villagers consume plenty of fuelwood each year.

To some extent, household energy consumption patterns in Houzhenzi *Xiang* Township are the same as those in the Laoxiancheng Village. Fuelwood is free and there are no limitations on its collection except the size. The principle difference is that most households in Houzhenzi *Xiang* Township use energy-saving stoves. Some other commercial energy sources with better efficiency have been also introduced to this town. However, little commercial energy was used here.

When lack of biomass is coupled with depressed economic circumstances, people use less energy [29]. This is the situation in the Mazhao Town where no fuelwood is available. The residents cannot afford commercial energy; they used crop residue for cooking. Although the efficiency of crop residue stoves is low, the quantity of crop residue is likewise small, thereby contributing little to total energy consumption. Having limited access to free biomass, local people do not customarily heat their houses in the winter. Consequently, overall energy consumption is much lower in the Mazhao Town than in the Laoxiancheng Village and the Houzhenzi *Xiang* Township.

Most people in the Zhouzhi County Town choose coal as their prime energy source because it is the cheapest. Unfortunately, coal is also the least efficient energy source. The overall economic level in Zhouzhi town is better than that of Mazhao. As a result,

households in the town use more energy than those in Mazhao. Also like the situation in Mazhao town, few residents heat their homes in the winter, which saves a large amount of energy.

In Xi'an City people use more efficient and convenient energy sources like natural gas and electricity—the efficiencies of which are several times greater than those of coal and biomass. With governmental and commercial encouragement, the idea of saving has become quite popular in Xi'an. Therefore, the total energy consumed per household in Xi'an City is the lowest among all sites studied.

Family size and family income are important factors in energy consumption. With a larger family size, more biomass or commercial fuel is consumed. However, when the family size is small those families consume more commercial energy in Houzhenzi *Xiang* Township and Mazhao Town. Those families are families of young couples who prefer using commercial fuel unlike their elders. The sizes of these new families are small because of the strict Family Planning Policy in China. The family income also affects the energy consumption. With the increasing of income, the consumption of biomass is decreasing and that of commercial energy is increasing. However, we saw the decline in consumption of biomass as household income increased was significant while the increase of commercial fuel use was not obvious though the correlation was significant, that pattern probably was due to the rigidity in energy consumption and the maximum energy requirement in households.

4.3. Spectrum of energy consumption

From village to city, the energy consumption spectra in households change.

In the Laoxiancheng Village, almost all energy is spent on cooking and heating; no energy is used for recreation. In Houzhenzi *Xiang* Township, cooking used the greatest energy draw. A large ratio of energy was used for heating in both Laoxiancheng Village and Houzhenzi *Xiang* Township, following the old, traditional custom of burning woods in the winter. Electricity in the Houzhenzi *Xiang* Township is only used for illumination and some electric appliances like TV.

There are almost no customs of heating in the Mazhao Town and the Zhouzhi County Town in winter. Most of the energy the residents consumed was for cooking. The amount of energy used for illumination and recreation was low, but the trend is to increase.

Compared to the other four study sites, the lifestyle of citizens in Xi'an City was more comfortable. Although cooking still consumed the most energy, the amount was much lower than that of rural areas and towns. Electricity consumption is a much more important component of energy consumption. Heating in winter and using private vehicles is more popular in the city.

With the development of urbanization and economics, people use less energy for basic necessities of life, such as cooking, and more energy for recreation.

5. Conservation implications

Energy use should be based on sustainable development and the betterment of ecological conditions in developing countries [22]. Currently the Chinese government is carrying out a series of policies to improve the living standards for rural residents. One of the most important of these processes is acceleration of the urbanization process in rural areas.

Energy consumption structure should also be changed to improve the livelihood and living standards observed in rural areas [21]. This prompts the question: what measures should be taken to facilitate urbanization?

For households in villages, it is necessary to improve the end-use efficiency of households and to decrease the total energy consumption. We do not expect commercial energy sources, such as LPG and coal, to become popular in rural areas. Considering the rich biomass resources near most villages, biomass residues will likely remain viable solutions for villagers. Although these fuels are not as "clean" as LPG, improvements in fuelwood stoves and innovations in residue stoves could provide efficient alternatives. The promotion of such technologies would help reduce the impact of fuelwood demand on fuelwood harvesting. For places where water resources are rich, hydropower could be developed to produce electricity for illumination and other small electric appliances, thereby decreasing the pressure on biomass collection.

For the households in towns in agricultural areas, residents could use crop residue or livestock dung to produce biomass gas for cooking, thus reducing the use of coal. For households in the county, where coal remains the primary energy resource, the government should take measures to develop the equipment needed to generate access to natural gas and other cleaner energy sources, thereby replacing coal step-by-step.

For people living in the city, it seems that their energy consumption is lower. However, the population density in the city is much higher than that in villages and the larger part of indirect energy consumption (i.e., the energy that is embodied in goods and services purchased by consumers) is not discussed here [30]. Thus, the most important thing for households in the city to learn is how to save energy. Some research supports this idea, showing that changing consumer behavior is generally considered to be an option to reduce energy consumption [31].

6. Conclusions

From village to city in central China, the patterns of energy consumption vary substantially. The energy choices shift from free biomass to cleaner commercial sources like LPG, electricity and natural gas. As lifestyles become more urbanized, the proportion of energy used for cooking also decreases, except among the few households requiring heat in the winter, as seen in the Mazhao Town and the Zhouzhi Town. Likewise, the proportion of energy used for recreation and electricity end uses also increases. For homes in villages, for example, it was necessary to decrease the total energy consumption to improve end-use energy efficiency. Households in townships in agricultural area should use crop residue or livestock dung to produce biomass gas for cooking, thereby reducing the use of coal. Households in county towns should use natural gas and other cleaner energy resources to replace coal step-by-step. For household in the city, in contrast, saving energy becomes important due to its dense population.

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